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Proton angular distributions from $d+D$ reaction for deuteron energies 0.5—0.9 MeV

By Zdzisław Sawa

With 2 figures in the text

Introduction

The well-known nuclear reaction

$$d+D \begin{array}{l} \to p + \mathrm{H}^3 + 4.04\ \mathrm{MeV} \\ \to n + \mathrm{He}^3 + 3.26\ \mathrm{MeV} \end{array}$$

has been studied for different incoming deuteron energies. In the present investigation the angular distributions of protons for 5 deuteron beam energies, from 0.5 to 0.9 MeV, were measured. This was done by means of the equipment of the Cockroft-Walton accelerator at the Nobel Institute, which includes a double-focusing magnetic heavy-particle spectrometer. These experiments were carried out in an attempt to obtain a more complete picture of the behaviour of the energy dependent asymmetry coefficients in the theoretical, ab initio, expression for angular distribution of protons in this reaction. Previous measurements showed that the trend in the values of the coefficients for deuteron energies below 0.5 MeV [ref. 1] was slightly different from the trend above 0.9 MeV [ref. 2].

Experimental arrangements

The apparatus used has been described earlier [ref. 3] as also the experimental arrangements used in investigations of angular distributions of charged products of nuclear reactions [ref. 4]. The thin targets were produced by bombarding the rolled aluminium foils, of approximately 150 μg/cm^2 thickness, in the isotope separator [ref. 5] by the D^+ beam. The proton distributions were examined at angles $15° < \theta_L < 135°$ and for energies of the incoming deuteron beam of 0.5, 0.6, 0.7, 0.8 and 0.9 MeV stabilized within 5 keV. The calibration of the current settings for the beam energy analyzing magnet was done with the well-known γ-resonances in Li $+ p$ (441 keV) and $F + p$ (672 and 874 keV).

Results and discussion

In fig. 1 are shown the experimental points of the distribution. The statistical errors are $2\% < \varepsilon < 3\%$; no attempt was made to estimate others. The lack of some

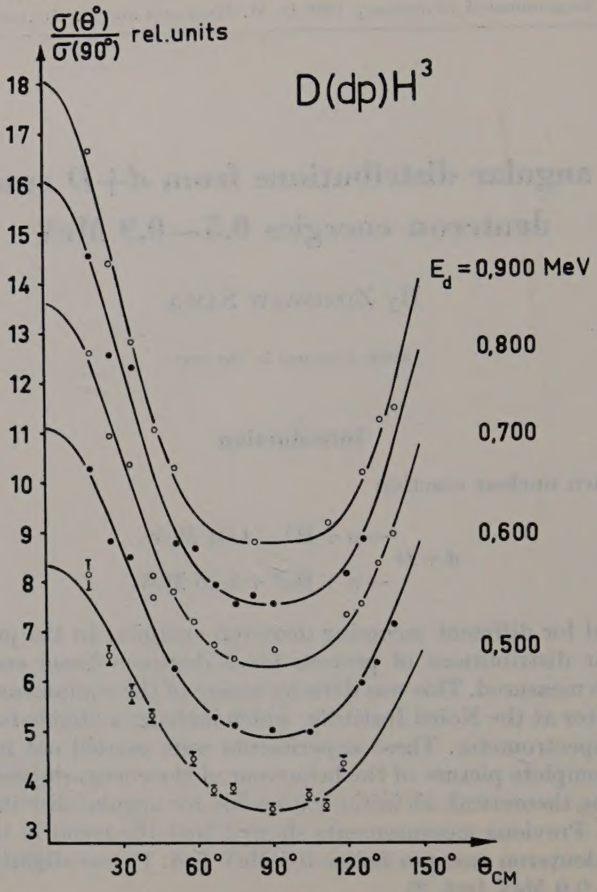

Fig. 1. Angular distribution of protons from the $d + D$ reaction in relative units as a function of $\theta^\circ_{\mathrm{cm}}$ and $E_{d\,\mathrm{lab}}$. The curves drawn are the best fit of the expression

$$d\sigma = \text{const.}\ [1 + A(E)\cos^2\theta + B(E)\cdot\cos^4\theta]\,d\,\Omega_{\mathrm{cm}}$$

to the experimental points. Distributions for E_d above 0.5 MeV are shifted upwards 1 unit relative to the proceeding one.

points in the vicinity of $\theta_L = 110^\circ$ is caused by the interference of the $d + C^{12}$ ground-state proton group with the $d + D$ protons.

In spite of the liquid air trap above the target, the build-up of carbon on the target foils was rapid. This could, of course, be prevented more effectively to a certain extent but it was deamed unnecessary as there are sufficient points in the distributions and as these distributions are symmetrical in the c.m. system as a consequence of the identity of the bombarding and target nuclei. The nuclear emulsions used as detectors were scanned in strips 0.25 mm broad every 0.5 mm, and in the vicinity of $\theta_L = 100^\circ$ every distribution was drawn in order to exclude those which show interference between the $d + D$ and $d + C^{12}$ protons. The spread of the experimental points is caused mainly by the monitoring system used, namely an integration of the deuteron beam. It is believed that the use of, for example, a scintillation detector

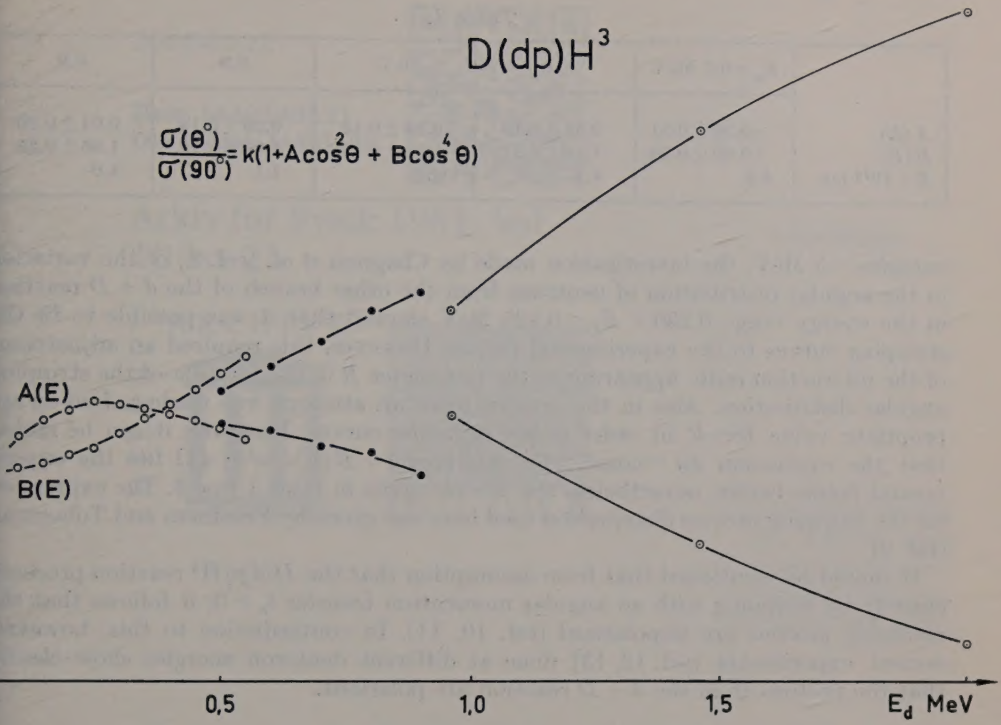

Fig. 2. The energy dependent asymmetry coefficients $A(E)$ and $B(E)$. To the left results of Wenzel. *et al* [ref. 1], in the center the results of the present investigation and to the right results of Blair *et al.* [ref. 2].

as the monitor placed at forward angle could reduce the contribution from this source of error.

At the energies below 5 MeV a theoretical description of this reaction has been given by Beiduk *et al.* [ref. 6] and it has been quite successful in explaining the angular distributions from the $d + D$ reaction.

The curves in fig. 1 represent the best fit of the expression given in ref. 6 $d\sigma =$ const. $[1 + A(E)\cos^2\theta + B(E)\cos^4\theta]\ d\Omega_{\mathrm{cm}}$ to the experimental points. In table 1 the energy dependent coefficients computed by the least squares method are explicitly given. A comparison of the results of Wenzel *et al.* [ref. 1] and Blair *et al.* [ref. 2] with the result of this experiment is made in fig. 2. From this it can be seen that there is no serious discrepancy between the results of Wenzel *et al.* at $E_d < 0.6$ MeV and those of Blair *et al.* at $E_d > 0.9$ MeV. It should be mentioned that the deuteron beam energies used in this experiment are in vicinity of the Coulomb-barrier height for the $d + D$ system and the results show no rapid change in the distributions which would indicate other contributions due to the Coulomb- or nuclear-distortion effects on the incoming or outgoing waves.

Another assumption is that the $D(dp)H^3$ reaction can proceed by a stripping process. This was theoretically examined by Fairbairn [ref. 7]. In spite of the suggestion presented in this ref. that stripping becomes the dominant process first at

Table 1.

	$E_d = 0.5$ MeV	0.6	0.7	0.8	0.9
$A(E)$	$+0.56 \pm 0.31$	0.50 ± 0.15	0.34 ± 0.12	0.29 ± 0.14	0.01 ± 0.20
$B(E)$	$+0.89 \pm 0.36$	1.14 ± 0.21	1.38 ± 0.17	1.60 ± 0.19	1.95 ± 0.25
$R \times 10^{13}$ cm	4.6	4.4	4.3	4.1	4.0

energies > 5 MeV, the investigation made by Chagnon *et al.* [ref. 8] of the variation in the angular distribution of neutrons from the other branch of the $d + D$ reaction in the energy range $0.250 < E_d < 0.825$ MeV showed that it was possible to fit the stripping curves to the experimental points. However, this required an adjustment of the interaction radii, appearing as the parameter R in the formula of the stripping angular distribution. Also in the present work an attempt was made to find an appropriate value for R in order to get stripping curves. However, it can be stated that the expression $d\sigma = \text{const.}\ [1 + A(E)\cos^2\theta + B(E)\cos^4\theta]\ d\Omega$ fits the experimental points better, nevertheless the R's are given in table 1 row 3. The expression for the stripping process distribution used here was given by Friedman and Tobocman [ref. 9].

It should be mentioned that from assumption that the $D(dp)H^3$ reaction proceeds entirely by stripping with an angular momentum transfer $l_n = 0$, it follows that the emerging protons are unpolarized [ref. 10, 11]. In contradiction to this, however, several experiments [ref. 12, 13] done at different deuteron energies show clearly that the protons from the $d + D$ reaction are polarized.

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